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AN EVALUATION OF BAKELITE BACKED CONSTANTAN FOIL STRAIN GAGES TO 600°F

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AN EVALUATION OF BAKELITE BACKED CONSTANTAN FOIL STRAIN GAGES TO 600°F

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FOREWORD

This report was prepared in the Data Acquisition and Processing Group, Structures Test Branch, Structures Division of the Air Force Flight Dynamics Laboratory, under Project No. 134A.

This report covers a period of work conducted from March 1965 to July 1966 Manuscript was released by the author November 1966 for publication as an RTD Technical Report.

Acknowledgment is extended to Messrs. Frederick E. Hussong, John F. Miller, and Edward J. Osborne for many helpful discussions.

This technical report has been reviewed and is approved.

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ABSTRACT

This evaluation was conducted in support of an elevated temperature fatigue test program.

The measurement of strain at temperatures up to 600°F using a 450°F rated bakelite backed, constantan foil strain gage is described. This gage was found to be usable up to this temperature.

TABLE OF CONTENTS

SECTION I

INTRODUCTION

A real-time fatigue test program on a titanium structure required strain measurements varying between 1000 and 2000 micro-strain at temperatures up to 600°F.

In the body of this test is the evaluation of the strain gage installation and a report on performance.

SECTION II

DISCUSSION

OBJECTIVE

The objective of this research was to evaluate the extension of the temperature range of the Baldwin-Lima-Hamilton FAB-25-12-S5 strain gage on 6 Al4V titanium up to 600°F.

The FAB-25-12-S5 gage is a bakelite backed, constantan foil gage, 0.25 inches in length, 120 ohm nominal resistance, and designed for use at temperatures not exceeding 450°F. This lot of gages were temperature compensated for titanium. The titanium compensation was obtained by special order.

In order to obtain valid strain readings certain characteristics of high temperature gages were considered to be important to this evaluation program.. These include:

a. Apparent strain vs. temperature relationship

b. Drift at temperature

c. Creep at temperature and load

d. Gage factor change at temperature

e. Run-to-run and gage repeatability of the above characteristics.

CHOICE OF INSTALLATION

Since the cement used to attach the gage and the protective coating used on the gage were known to affect the above listed characteristics, several combinations of cements and coatings were investigated. These various combinations were:

CEMENT	COATING
Mithra	None
"	QF 180
EPY 400	None
"	QF 180
"	Gage Coat No. 6
"	RTV 102
"	RTV 106
"	Astro Ceram A
EPY 500	RTV 106

Of these combinations only EPY 400 or EPY 500 with an RTV 106 silicone rubber coating were acceptable. The other materials were rejected for the following reasons:

Mithra Cement - Installation exhibited high drift rates at 600°F

QF 180 - Too brittle and required too much surface abrasion to adhere.

Astro Ceram A - Too brittle

Gage Coat No. 6 - Oxidizes at temperature over 500°F.

RTV 102 - Cracked at 600°F.

Further, the installations examined without a coating resulted in oxidation of the bakelite backing.

The superiority of the EPY 400 or EPY 500 cement with RTV 106 coat was readily established by simple time at temperature runs so that the remainder of the evaluation only concerned this combination.

PROCEDURE

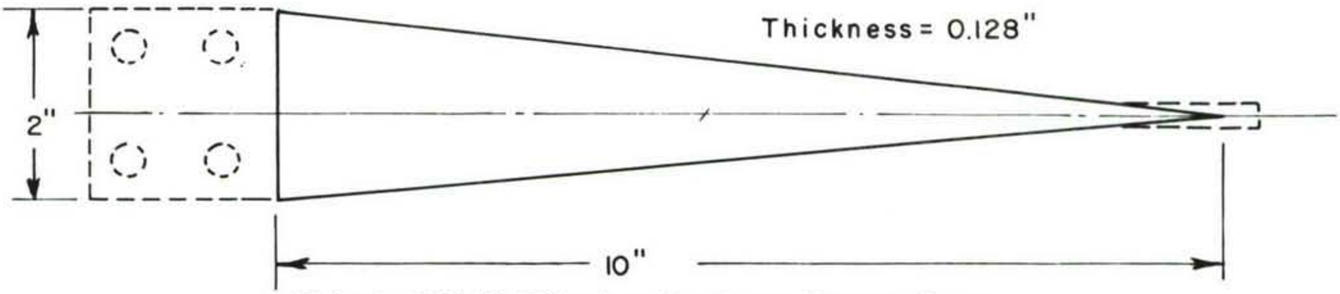
The circuit conditions were:

(1) Five wire single active arm bridge

(2) Voltage calibration shunt resistance - 54K

(3) Voltage calibration output - 4.00 M.V.

The gages were installed on 10 inch 6A14V titanium constant stress beams. The beams were mounted in a high temperature strain gage calibration rig.



10 Inch 6Al4V Titanium Contress Stress Beam

A stepping block with deflection steps of .250" was used to deflect the beam. The top step caused a total beam deflection of one inch.

$$\epsilon = \frac{yh}{L^2}$$

where:

ϵ = Micro-strain, in inches/inch

y = Deflection, in inches

h = Beam thickness, in inches

L = Beam length, in inches

Since the load was a bending load and the gage filament was actually slightly off the beam surface, a correction for strain experienced by the gage was necessary.

With the gage filament being 0.002 inch above the specimen and assuming no shift in the neutral axis, the following correction in strain was made:

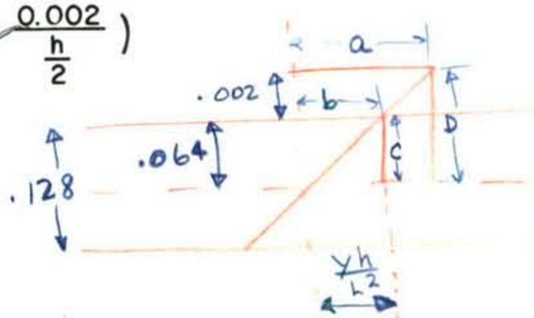
$$\epsilon_{corrected} = \epsilon \left(\frac{\frac{h}{2} + 0.002}{\frac{h}{2}} \right)$$

$$\frac{b}{c} = \frac{a}{D}$$

$b = 1280\ \mu\epsilon$

$a = 1320\ \mu\epsilon$

$$\frac{\frac{yh}{L^2}}{.064} = \frac{a}{.066}$$



For the 10 inch beam of 0.128 inch thickness and a deflection of 1 inch the corrected strain was:

$$\epsilon_{corrected} = \frac{yh}{L^2}\left(\frac{h}{2} + \frac{0.002}{\frac{h}{2}}\right)$$

$$= 1320 \text{ micro-strain}$$

Toward the determination of gage factor variation with temperature, the temperature was increased in 100°F increments from 100° to 600°F. At each level an apparent strain record was made. After apparent strain at temperature became repeatable, run-to-run, the temperature levels were maintained to check the drift characteristics. If after 1/2 hour at a temperature no significant drift was observed, the temperature was increased to the next level. When drift was encountered, the temperature level was maintained until the drift rate became constant.

Using the constant stress beam, creep data were recorded with 330, 660, 990 and 1320 micro-strain loads at temperature. The decrease in gage factor was calculated using the formula:

$$G.F. = \left(\frac{\epsilon_{corr.}}{\epsilon_{cal}}\right)\left(\frac{R_g}{R_g + R_{cal}}\right)\frac{1}{\epsilon}$$

where:

G.F. = Gage Factor

$\epsilon_{corr.}$ = Signal minus zero unbalance in millivolts

ϵ_{cal} = 4.00 millivolts

R_g = 120 ohms

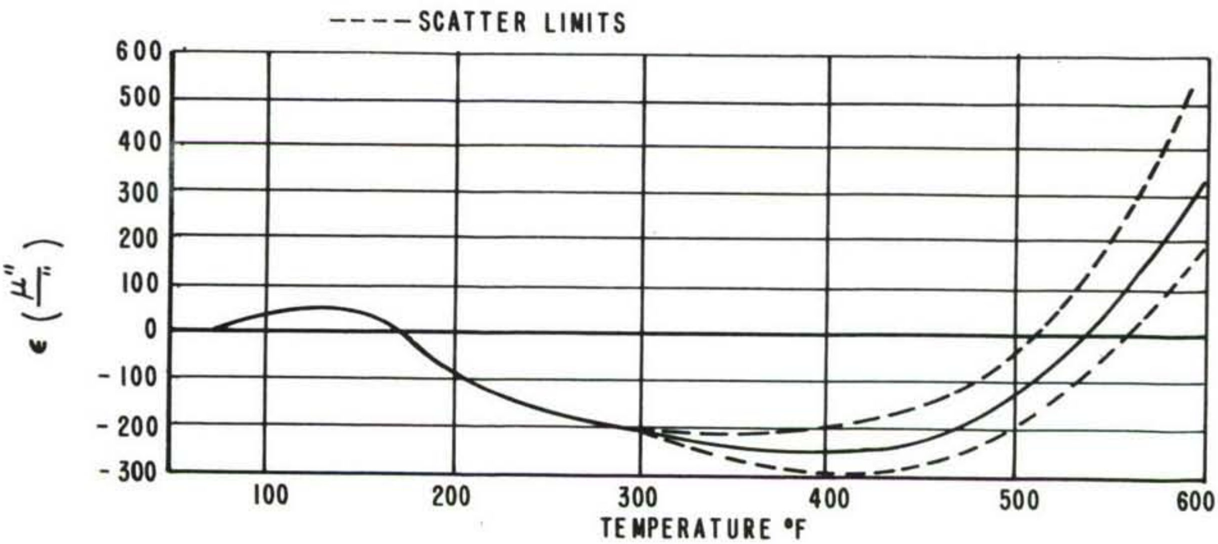
R_{cal} = 54K ohms

ϵ = Strain level in inches/inch

To check repeatability, five strain gage installations were cycled at least three times each with data being recorded and compared.

RESULTS

a. Apparent Strain vs. Temperature



$$\frac{b}{c} = \frac{a}{D}$$

$$a = b\,\frac{D}{c} = \frac{yh}{L^2}\,\frac{(0.002 + h/2)}{h/2} = \frac{yh}{L^2}\left(\frac{0.002}{h/2} + 1\right)$$

$$\epsilon_{\text{corrected}} = \frac{yh}{L^2}\left(1 + \frac{0.002}{h/2}\right)$$

Repeatability checks showed no significant scatter at temperatures under 350°F. At 400°F apparent strain data varied ±40 micro-strain from the above curve and at 600°F data scatter varied as much as ±75 micro-strain.

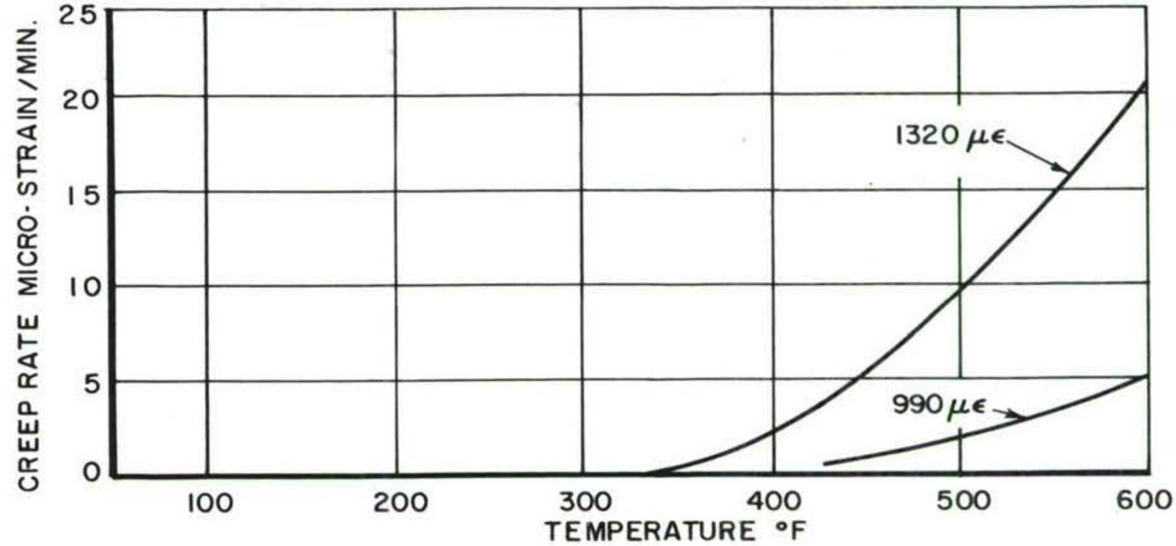
b. Drift

First and second cycle drift characteristics were significant at temperatures over 400°F. The highest drift rate was +1.5 micro-strain per minute. This was observed at temperatures greater than 550°F and was indicated on the first heat cycle to 600°F.

Drift analysis of the third and subsequent heat cycles indicated no significant drift at temperatures less than 550°F.

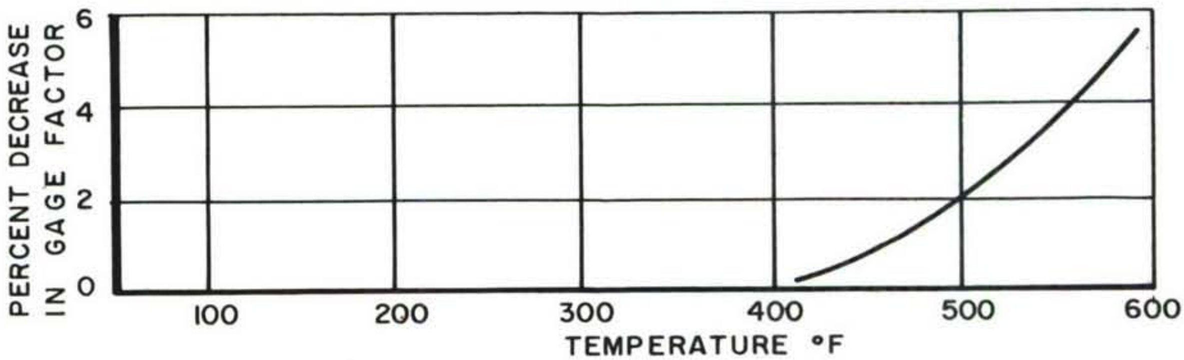
c. Creep

Creep was negligible at temperatures less than 400°F. Above this temperature and at strains over 1000 micro-strain, creep became significant.



The characteristic drift at temperature was a notable part of creep data at temperatures over 500°F. The drift function added to or subtracted from the creep data depending upon whether the test beam was loaded in compression or tension.

d. Gage Factor vs. Temperature



Decrease in gage factor was insignificant at temperatures less than 400°F.

APPLICATION AND OBSERVATIONS

Sensors similar to the above evaluated gages were installed upon and have been used for strain measurement of the physical responses of a titanium structure for nine months.

The test environment included fatigue cycles to maximum stresses of 25,000 psi and temperatures to over 425°F. This test program is currently running 16 hours a day at an average total of 5000 cycles per day.

Periodic checks on zero return at room temperature and at no-load conditions showed less than 25 micro-strain offset during a time period involving several days. Moisture problems, usually problems of considerable concern, were precluded because of the continual heat cycling.

The strain gage installations were observed to be very consistent in following the temperature compensation Apparent Strain versus Temperature curve even at temperature rise rates approximating 4°F/sec. Performance at higher rise rates was not evaluated.

Of the 24 originally installed strain gages there have been no installation failures. The demonstrated reliability of these gage installations has been an important factor in enabling predictable behavior.

SECTION III

CONCLUSIONS

The Baldwin-Lima-Hamilton FAB-25-12-S5 strain gage installed upon 6Al4V titanium with EPY-400 or -500 epoxy cement and coated with RTV 106 silicone rubber is usable with performance predictability and a minimum of correction factors to 500°F. Between 500°F and 600°F the gage installation becomes quite sensitive to temperature effects; however, this sensitivity does not negate the installations usefulness. It does require that considerations be given to the effects of drift and creep at temperatures in excess of 500°F and at induced strain levels greater than 1000 micro-strain. The effects of drift and creep are not extremely significant in magnitude, as the text of the report illustrates, but the use of correction curves and/or conversion constants are recommended for acquisition of reliable information. Considering this recommendation, this evaluation indicates that the strain gage installation as described will repeatedly yield valid data under conditions of an extended temperature range up to 600°F.

SECTION IV

REFERENCES

1. Robert W. Troke, Strain Gage Instrumentation for Flight Test Fatigue Measurements, SESA Annual Meeting, 1964.

2. Nelson D. Wolf, Summary of Strain Gage Fatigue Data, Technical Documentary Report No. ASD-TDR-63-202, April 1963.

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